Automatic Change Detection and Classification (ACDC) System

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Abstract

The Naval Research Laboratory is developing an Automatic Change Detection and Classification (ACDC) system for the Naval Oceanographic Office to use with sidescan sonar imagery (SSI). The ACDC system will automatically detect seafloor features in SSI; classify, catalog, and cluster the features; and compare them with features previously detected (and stored in historical databases), to determine whether each newly detected feature has simply moved, relative to a previously plotted position, or is actually new (change detection). This research project is on going, with an estimated completion date of 2006. The first two components of ACDC – computer aided detection and computer aided classification – have been completed and fully tested. This year, dynamic database components are being implemented and further work is being performed on two wavelet networks for feature and area matching (i.e., change detection).

Acronyms

ACDC	automatic change detection and classification
AM	area matching
AUV	autonomous unmanned vehicles
CAC	computer aided classification
CAD	computer aided detection
DB	database
DB-H	DB of **H**istorical SSI features and snippets
DB-S	DB of ideal feature **S**hapes
DB-V	geospatially searchable **V**ector feature DB
FM	feature matching
GPS	global positioning systems
MILEC	mine-like echo
NAVOCEANO	Naval Oceanographic Office
NRL	Naval Research Laboratory
ONR	Office of Naval Research
SPAWAR	Space and Naval Warfare System Command
SSI	sidescan sonar imagery
SSS	sidescan sonar system
WN	wavelet network

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Introduction

The Naval Research Laboratory (NRL) is developing an Automatic Change Detection and Classification (ACDC) system for the Naval Oceanographic Office (NAVOCEANO) to use with sidescan sonar imagery (SSI). This system will support the detection, classification, clustering, and change detection of seafloor features, including mines, in support of fleet operations by speeding up the "detect to engagement" timeline in a mine warfare environment.

Historically, this effort has been manually performed either on-scene or via "reach back" to NAVOCEANO. The integration of the ACDC system onboard naval mine hunting vessels will allow in-stride "automated" change detection to determine the presence or absence of mines, thus reducing mine clearance timelines and developing an accurate assessment of risk to follow-on naval forces.

This paper describes how the ACDC system will perform the following functions:

- Automatically detect seafloor features in SSI collected by a sidescan sonar system (SSS);
- Classify, catalog and cluster the features;
- Compare new features with those previously detected (and stored in historical databases), to determine whether each newly detected feature has simply moved, relative to a previously plotted position, or is actually new (change detection).

Background

In 2001, the Space and Naval Warfare System Command (SPAWAR) funded the authors to develop a fully autonomous and real-time computer aided detection algorithm and automatic clustering algorithm to identify and cluster features in SSI. Both algorithms are currently being enhanced for incorporation into the ACDC system.

Late in 2001, follow up work began on a multi-year 6.2 applied research project to develop an underwater positioning, navigation and timing system for multiple autonomous underwater vehicles (AUVs). The objectives for this project were to improve AUV positioning and navigation via feature-based terrain matching using SSI. The AUV would have an on-board feature database populated with features detected in historical SSI. The autonomous algorithms aboard the AUV would detect new features in real-time, match them with features in the on-board database, and use this information to correct the AUV position.

In 2003, NRL and NAVOCEANO scientists realized the same steps could be applied to automatic change detection. NAVOCEANO was specifically interested in using the NRL ACDC to identify newly placed objects on the seafloor that could potentially be explosive mines. To that end, SPAWAR and the Office of Naval Research (ONR) jointly funded an acceleration of the 6.2 project to implement and transition a fully functional ACDC system by the year 2006.

Sidescan Sonar Systems (SSS)

Acoustical waves through water are easily generated with modern acoustic transducers. When the waves are reflected back, details about the local morphology of the seafloor can be extracted. A SSS transmits an acoustical beam to each side of the transducer. The beams are emitted in a wide angular pattern down to the bottom, and the echoes are received back to create a narrow strip, called a ping, below and to the sides of the transducer track (Blondel and Murton, 1997). SSS, developed in the 1960's by Dr. Harold Edgerton at the Massachusetts Institute of Technology (MIT), transmits an acoustical beam on each side of the transducer called the "fish." Figure 1 depicts a towed SSS.

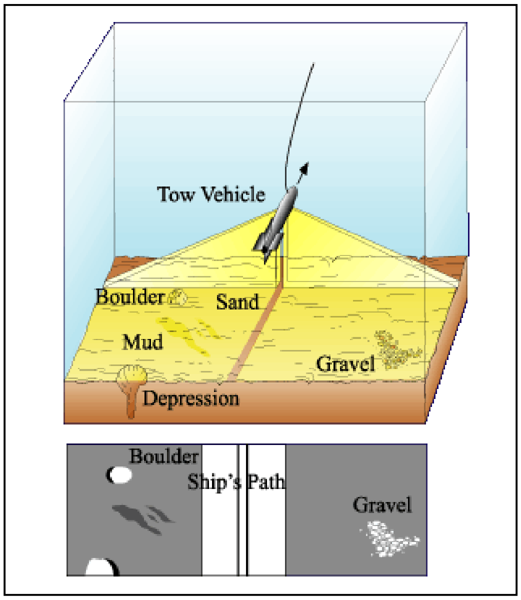

Figure 1. Towed SSS.

Each time the transducer pings (along-track resolution) the beams spread or fan out (across-track resolution). The amount of across-track spread is measured by the beam angle. The beams directly below the SSS spread out and never hit the bottom. The sonar is "blind" in this small gap, which is called nadir. Nadir is a term from astronomy defined in the American Heritage® Dictionary as "a point on the celestial sphere directly below the observer, diametrically opposite the zenith."

The SSS can be hull-mounted, towed from a platform such as a ship or helicopter, or carried on-board an AUV. The fish is usually equipped with pressure or altimeter sensors that allow it to follow the bottom, maintaining a constant height above the sea floor, or "fly" at a constant depth below the surface.

SSS is used to detect mine-like objects close to or on the seafloor. Such objects, also called mine-like echoes (MILECs) or simply clutter, show up in the SSI as bright spots with adjacent shadows that face perpendicular away from the nadir. Features of various shapes and sizes can be detected by the shadows in the image; the size of the shadow varies as a function of beam angle and feature dimensions (Fish and Carr, 1990). Figure 2 shows an example of a MILEC.

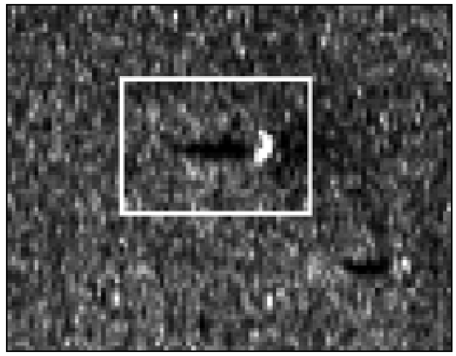

Figure 2. MILEC.

The pressure of an acoustic wave in a material is given by (Urick, 1983),

$$p = \rho c u \ , \qquad (1)$$

where ρ is the fluid density of the medium, c is the propagation velocity of the wave, and u is the velocity of the fluid particles. The particle velocity, u, acts like current and ρc acts like resistance and is called the specific acoustic resistance or (when complex) impedance. The pressure of the wave, p, behaves like voltage and the energy per second, or power, is found by:

$$I = \frac{p^2}{\rho c}, \qquad (2)$$

which is analogous to Ohm's Law (Urick, 1983). p is the instantaneous pressure, but due to the integration time inherent in the sonar, it is more useful to look at the squared pressure as an average over an interval of time. A more general approach is to write the equation in terms of *energy flux density*, or the acoustic energy per unit area of wave front:

$$E = \int_0^\infty I \, dt = \frac{1}{\rho c}\int_0^\infty p_2 \, dt \ . \qquad (3)$$

The intensity is the mean-square pressure of the wave divided by ρc and averaged over an integral of time length T, or

$$I = \frac{1}{T}\int_0^T \frac{p^2(t)}{\rho c} \, dt \ , \qquad (4)$$

so that over the time interval T,

$$I = \frac{E}{T}. \tag{5}$$

The quantity T is the time interval over which the energy flux density of an acoustic wave is to be averaged to form the intensity (Urick, 1983). The intensity from each ping is sampled to produce a scanline of grayscale intensity value from 0 (black) to 255 (white). When the scanlines are aligned adjacent to one other, a SSI is produced (figure 3).

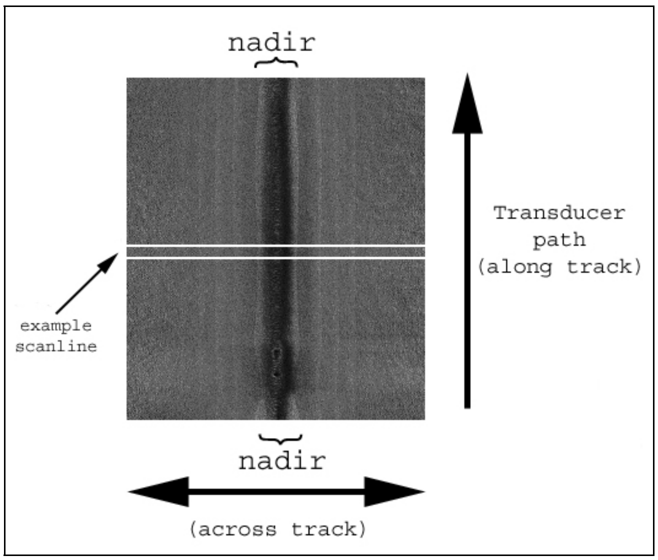

Figure 3. Sample SSI.

One type of the imagery used by ACDC comes from the Klein 5000 SSS (figure 4), which uses ten beams (five on each side). The center frequency is 455 kHz with a pulse length ranging from 50 to 200 μ sec, which gives a 20 cm along-track resolution. The across-track resolution is 36cm at a maximum of 150m, for an array 120cm long.

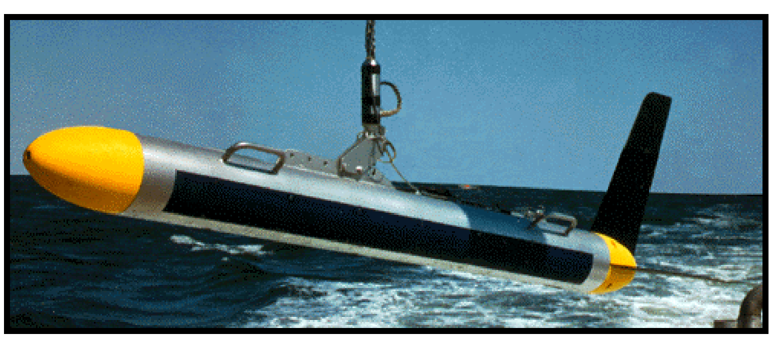

Figure 4. Klein 5000 SSS.

Problems with Sidescan

Correlation between pixels in SSI is affected by coherent "speckle" noise that reduces effective resolution and hampers the detectability of targets and features in the imagery. SSI may also contain phantom features created by surface return when the sonar is in shallow water or when the fish is pitched at a few degrees or more. GPS signal dropout can cause the image processing software to lose or duplicate scanlines. Any automated feature detection method applied to the imagery must be robust and able to handle these processing issues.

Bottom objects and features can change and migrate over time due to ocean currents and burial. Even when objects remain static, a big issue with SSS is position error. The center latitude/longitude position of each ping contains position error, due to GPS error and error from the cable layback model (figure 5). Because the Klein 5000 is usually towed through the water with a cable attached to a tow platform, large positioning errors are sometimes introduced. GPS is usually used to obtain the position of the tow platform, but not for the towed sonar because GPS will not work underwater.

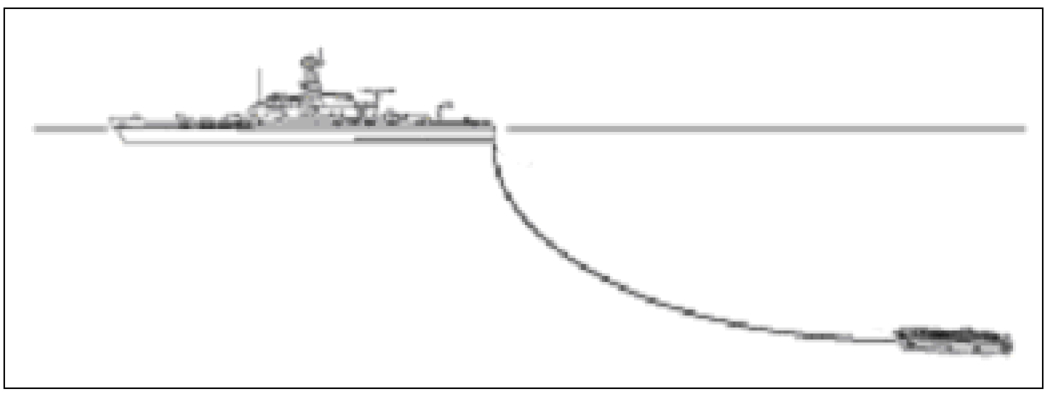

Figure 5. Cable Layback Model.

ACDC System

The NRL ACDC system is comprised of five key components:

1. The Computer Aided Detection (CAD) component is a real-time detection algorithm capable of detecting objects in SSI with bright spots and shadows (figure 6).
2. The Computer Aided Classification (CAC) component identifies and classifies the features. CAC uses an adaptive filter to "complete" the feature's bright spot, based on the shadow, and then classify the feature based on the dimensions of the completed bright spot and the shadow (figure 7).
3. Three databases (DB) support classification and change detection. The first is an historical DB (DB-H) containing SSI from past surveys, snippets of classified features, and attributes pertaining to the features (figure 8). The second is an ideal shapes DB (DB-S) containing ideal depictions of real features that might be encountered during a survey (figure 9). The third is a geospatially searchable vector feature DB (DB-V) that stores the classified historical features and facilitates the fast retrieval of these features based on geospatial areas

of interest. The retrieval process corrects for estimated position errors (e.g., feature migration, GPS) using geospatial bitmaps of increasing resolution (Gendron, et al. 2001). A two-step search attempts to match each new object with one in the DB-H. If all attempts fail, then the object is marked as a new object not seen before in the historical data (figure 10).

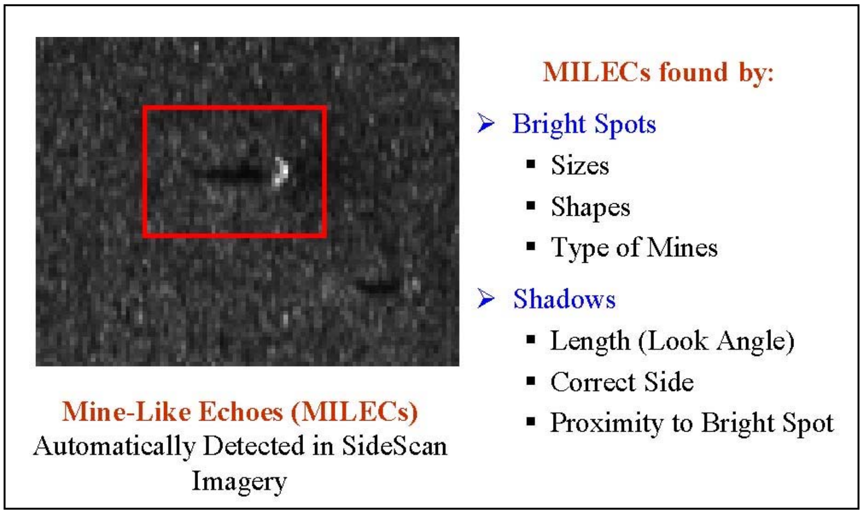

Figure 6. NRL CAD.

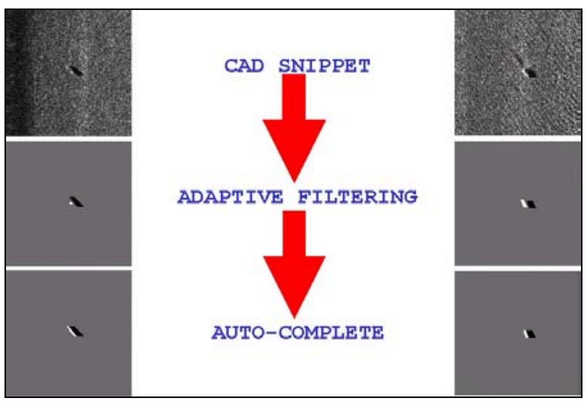

Figure 7. NRL CAC.

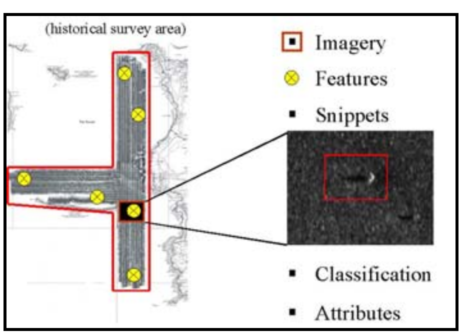

Figure 8. DB-H.

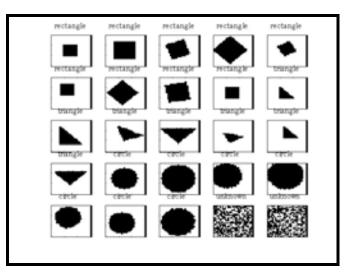

Figure 9. DB-S.

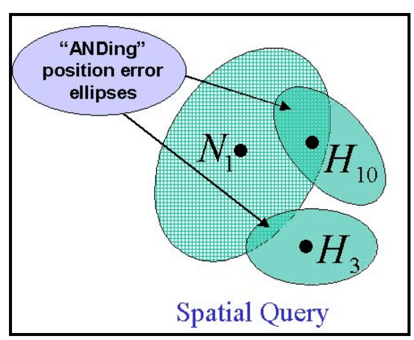

Figure 10. DB-V.

4. The computer-aided Feature Matching (FM) component uses a Wavelet Network (WN) that inputs wavelet coefficients to a neural network and matches historical features (determined from the fast searchable DB-V) with newly detected and classified features (figure 11). WNs are proven to work well at matching features and are used extensively in face recognition, for example (V. Krueger and G. Sommer, 2000).

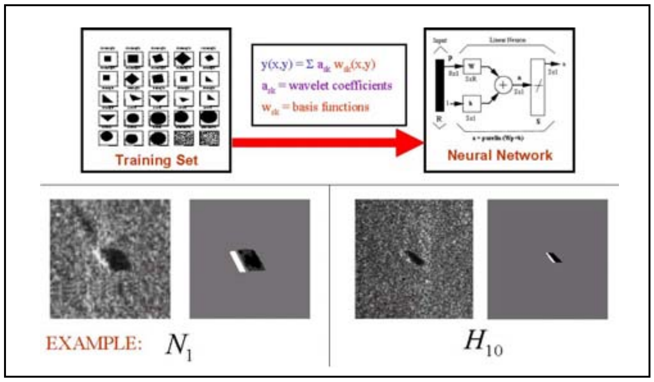

Figure 11. FM WN.

5. The computer-aided Area Matching (AM) component matches larger areas (clustered features) to reduce the false detection rate of the FM component. The AM component uses a separate WN and a single-pass clustering algorithm developed earlier by NRL (figure 12).

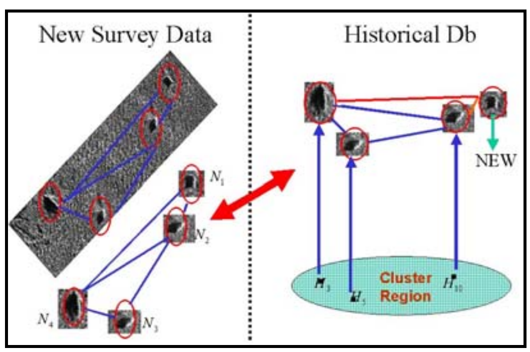

Figure 12. AM WN and clustering.

Conclusions

NRL plans to complete this project and transition a fully functional ACDC system to NAVOCEANO in support of mine warfare requirements by 2006. The CAD component of ACDC automatically detects seafloor features (e.g., mine-like objects) in SSI; the CAC component will use three supporting databases to classify and catalog those features, and the WN-based FM and AM components will perform change detection and feature clustering. The CAD and CAC algorithms have been completed and fully tested. The supporting DBs are being implemented this year, and further work is being performed on the WNs for AM and FM.

Concurrent and future work planned in support of this project includes a structured task analysis of manual detection, classification and clustering strategies to determine how best to automate these functions. Unfortunately, different analysts often “call” contacts differently, and even an expert analyst might detect or classify the same contact differently on repeat trials. Presumably, the benefits of a successful automated ACDC system will be faster, more accurate, and consistent/repeatable detection and classification, ultimately resulting in reduced labor and time requirements and safer, more successful mine countermeasures operations. To maximize these potential benefits, NRL plans to perform statistical analyses of manual vs. autonomous methods of detection, classification and clustering as part of the validation and verification of ACDC.

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